1

A FIELD EVALUATION OF THE KERN DKM3-A ASTRONOMICAL THEODOLITE FOR PRECISE ASTRONOMIC POSITION DETERMINATION

by

William Eugene Carter
The Ohio State University

1965

A FIELD EVALUATION OF THE KERN DKM3-A ASTRONOMICAL THEODOLITE FOR PRECISE ASTRONOMIC POSITION DETERMINATION

A Thesis

Presented in Partial Fulfillment of the Requirements
for the Degree Master of Science

by

William Eugene Carter, B.S.
The Ohio State University
1965

Approved by

Ivan I. Mueller

Adviser
Department of Geodetic Science

PREFACE

This thesis presents the results of a field evaluation of the Kern DKM3-A Astronomic Theodolite.

The purpose of the study was to determine if the DKM3-A could be expected to provide "first-order" astronomic latitude and longitude values if the observing techniques, numbers of observations, and methods of data reduction such as those presently used by such organizations as the U. S. Coast and Geodetic Survey (7), and the 1381st Geodetic Survey Squadron (23), and suggested by Dr. H. Odermatt (14) were followed; and to evaluate the DKM3-A's practicability as a field instrument.

The conclusions reached are primarily based on observations made in September of 1964 at Station OAFB-60-B Orlando AFB, Orlando, Florida, by experienced observers from the 1381st GSS.

The text assumes that the reader is familiar with the procedures, instrumentation (other than the DKM3-A), and terminology peculiar to such work and therefore does not include detailed accounts or descriptions in these regards.

ACKNOWLEDGEMENTS

The author gratefully expresses his thanks to Lt. Col. R. B. Greenlees, Commander of the 1381st Geodetic Survey Squadron, and the members of his squadron for the gracious giving of their time and work, as well as the loan of necessary supplies and equipment, to help make this study as complete and meaningful as possible. A special thank you is extended to the men of the Astro Section that did the field observations: W. DeCostanza, W. Hutchinson, V. Stevens, and A. Smith. In addition to participating in the observing portion of the study W. DeCostanza served as supply agent, project coordinator, and correspondent throughout the entire project. His help was of incalculable assistance to the successful completion of the study.

Kern Instruments Inc., as represented by Mr. H. J. Wehrli, Vice President, suggested and accomplished the necessary instrument modifications in a most courteous and efficient manner. Without their complete cooperation the evaluation could not even have been attempted.

The author further expresses his thanks to the entire staff of the Ohio State University Department of Geodetic Science, and most particularly to Dr. I.I. Mueller, for their assistance and guidance throughout the study.

The typing, as well as a great deal of understanding and moral support, was contributed by my wife, Marilyn.

TABLE OF CONTENTS

TABLE OF CONTENTS
(continued)

TABLE OF CONTENTS (continued)

Chapter 1

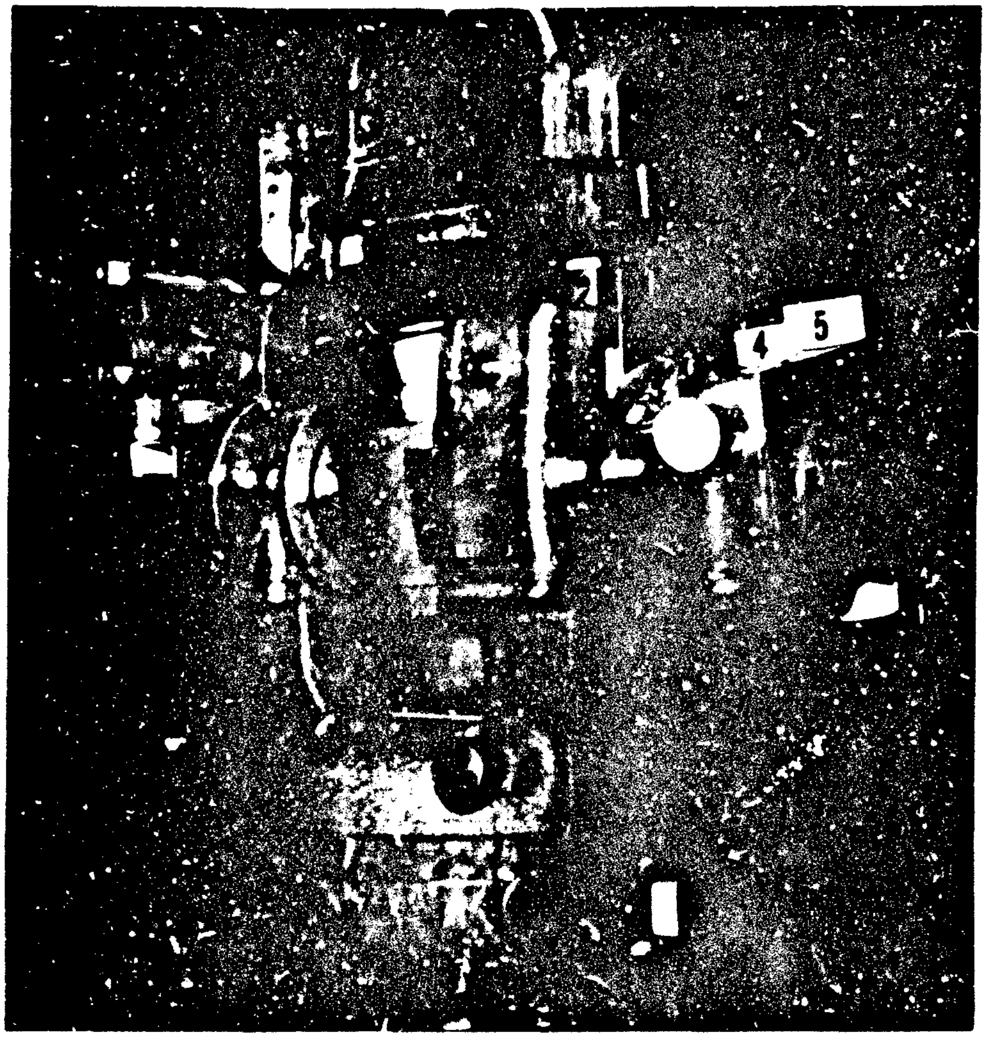
DESCRIPTION OF THE DKM3-A

1.1 Introduction

The DKM3-A is a variant of the Double Circle Triangulation Theodolite DKM3; the principal changes being those necessary to facilitate the addition of an astronomic micrometer. The Kern Company has continued to modify the DKM3-A, since it was first made available, in an attempt to produce an instrument with "first-order" capabilities, and has recently developed promising new striding level and double Horrebow level systems.

The instrument used during this study was purchased by Ohio State University in 1962 and was originally equipped with a striding level and a single Horrebow level that had been designed for the DKM3. The levels were relatively insensitive (approximately 4½ seconds of arc per 2 mm division), and tests revealed several other serious inadequacies. The striding level mount was too light weight and consequently very unstable. The single Horrebow level system was not heavy enough to properly counterbalance the astronomic micrometer and when it was attached, the instrument could not be properly leveled-thus making the Horrebow level useless.

Immediately prior to this study the instrument was updated by replacing the original striding and Horrebow levels with the newly developed systems. Detailed



1. Striding Level
2. Viewing Prism for Collimation Level
3. Focus Knob
4. Rheostatic Control Knob of Drum-Scale Lighting
5. Tracking Knob
6. Telescope Ocular
7. Drum-Scale Reading Eyepiece
8. Circle Reading Eyepiece
9. Astronomic Micrometer Clamp
10. Reading Micrometer Knob
11. Horizontal Circle Drive
12. Collimation Level Control Knob
13. Leveling Knot
14. Optical Plummet
15. Horrebow Levels

Figure 1 KERN ASTRONOMIC THEODOLITE - DKM3-A

descriptions of the improved levels are given in Section 1.7. Special low pitch leveling knobs and a single line tracking wire were also installed.

This chapter contains a brief description of the DKM3-A; further information can be found in (9) and (10). Figure 1 is a picture of the instrument used during this study.

1.2 Telescope

The telescope consists of a system of convergent lenses and concave mirrors so designed and arranged to provide a high degree of chromatic correction and excellent luminosity and resolving power, while eliminating undesirable stray light. (See Figure 2)

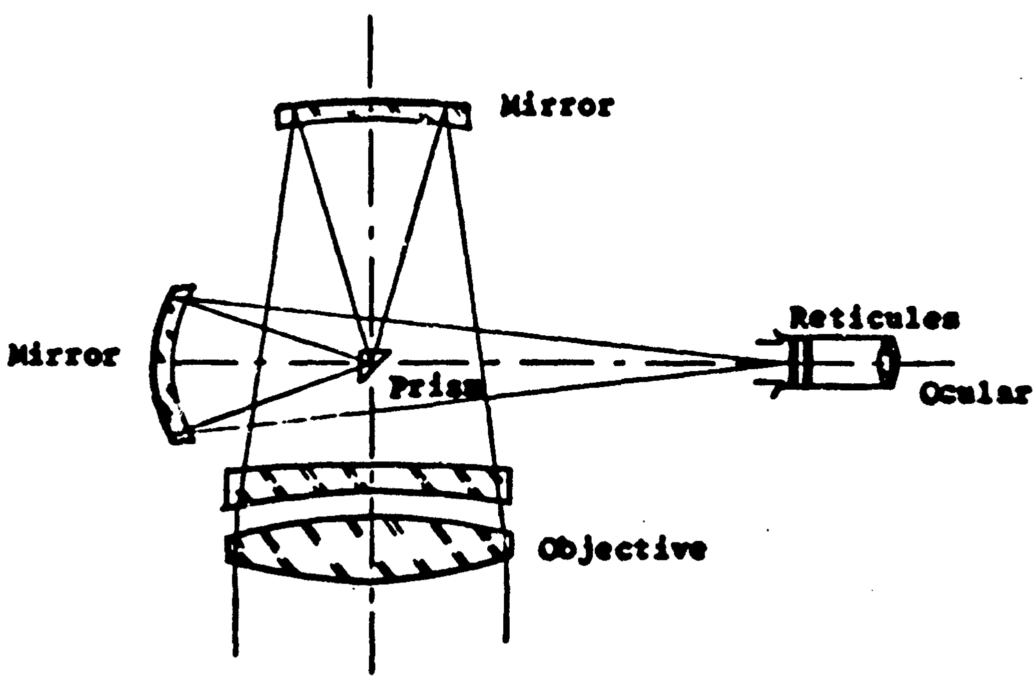


Figure 2 TELESCOPE COMPONENTS

The objective lens has an aperature of 72 mm and a focal length of 510 mm. Two interchangable eyepieces provide either 45X or 27X magnification. Focusing is accomplished by a drawtube arrangement controlled by the focusing screw that moves the entire eyepiece assembly parallel to the horizontal axis. Focus can be effected from approximately 19 meters to infinity.

The system is quite adequate to permit the use of stars as dim as 6.0 magnitude for longitude purposes and 7.0 for latitude determinations. Defraction screens are available for use during observations on bright stars - such as Polaris.

1.3 Reticule Patterns

The movable and fixed reticule patterns are shown in Figure 3.

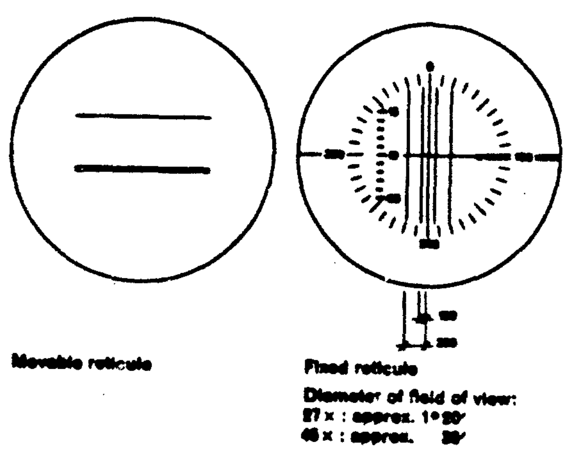


Figure 3 RETICULE PATTERNS

The movable reticule shown here is of the bifilar type commonly used in European countries. A single line type, more often used in the United States is also available.

The fixed reticule pattern is a composite of lines that are used for various purposes. The five parallel lines are used for observing star transits by the "eye and ear" method. The ten "tick marks" numbered from 05 to 15 correspond to whole turns of the micrometer and are used in conjunction with the movable reticule to measure azimuth or zenith distance differences. In addition, there is a system of azimuth graduations that may be used to orient the instrument in azimuth so that a particular star will pass through the center of the reticule - a condition necessary for certain observations.

1.4 Astronomic Micrometer

The DKM3-A is equipped with an astronomic, or impersonal, micrometer. As usual, the micrometer can be rotated 90° about its axis to facilitate measurements in either azimuth or zenith distance. While its basic functions are the same as those performed by any of the traditional astronomic micrometers, several improvements and observer conveniences have been incorporated into its design.

The Kern micrometer is completely optically read. To read the micrometer one first reads the number of whole

turns from the position of the movable wire in relation to the fixed field of reticules, and then reads the fractional part of the turn, or "drum value", through a special eyepiece located immediately adjacent to the telescope ocular. The drum scale is graduated into 120 divisions and each division is further divided into half. (See Figure 4) Alternate whole divisions are numbered from 0 to 118. The system is internally lighted, and the lighting intensity is controlled by a rheostat convenien-tly located on the micrometer housing.

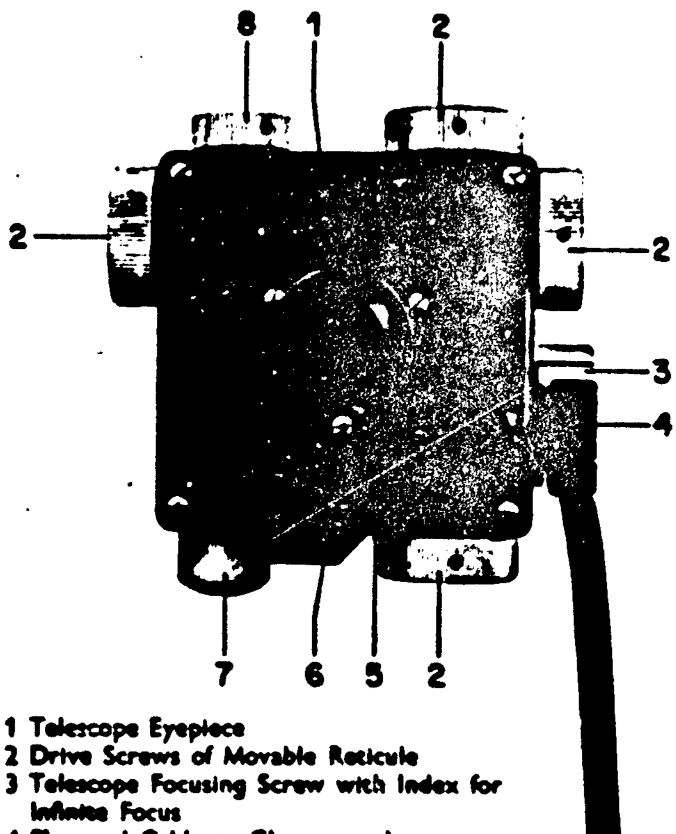
The resulting effect is to make it quite easy for an observer to estimate the micrometer value to the nearest 1/10 of a division, which corresponds to approximately 1/10 of a second of arc - equatorial value.

Drum scale of the eyepiece micrometer

Reading : 79.6 drum units
1 revolution = '20"/120 units

<u>Figure 4</u> EXAMPLE OF DRUM-SCALE READING

The movable reticule is controlled by two sets of tracking knobs reciprocally linked and situated at right angles to one another. Thus, whether the micrometer is in the azimuth or zenith distance measuring position, and regardless of the zenith distance at which the measurements



1 Telescope Eyepiece
2 Drive Screws of Movable Reticule
3 Telescope Focusing Screw with Index for Infinite Focus
4 Plug and Cable to Chronograph
5 Stop for Commutator Switching Lever in the «On» Position (The Lever does not show in the picture)
6 Reading Eyepiece of Drum Scale
7 Housing of Bulb for Scale Illumination
8 Rheostat for Adjusting Intensity of Scale Illumination

<u>Figure 5</u> ASTRONOMIC MICROMETER

are being made, one set of tracking knobs is convenient.

A plug on the micrometer housing provides the connections for a chronograph cable. In each full turn of the micrometer ten scaling breaks and one identification break are registered. The scaling breaks are very nearly equally spaced at 12 division intervals, from 0 to 108

inclusive, and the identification break is at an approximate drum reading of 4 . When the registering apparatus is not required, the commutator may be made inoperative by means of a switch located on the micrometer housing. (See Figure 5)

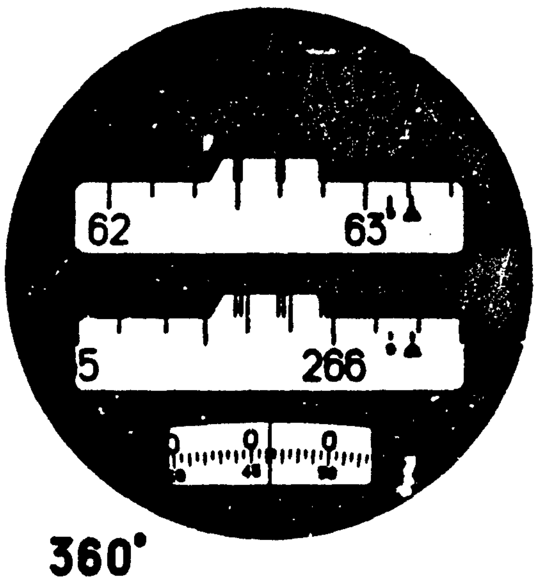
1.5 Autocollimating Eyepiece

A factory installed autocollimating eyepiece is available upon request. The illuminator is permanently mounted on the micrometer housing and is connected to the instrument lighting system. The bright lines of the autocollimating diagram appear against a dark background. The diagram and the fixed reticule are on surfaces of a beam splitter cube. The lines of sight determined by the fixed reticule and bright-line pattern are aligned to each other within 0.5 seconds of arc. Both the fixed reticule and the movable reticule can be used for autocollimation in combination with the bright-line pattern. The autocollimating system does not decrease the total telescope magnification.

1.6 Circles

The DKM3-A is a reiterating theodolite. The horizontal circle can be displaced in either direction any desired amount by use of the circle orienting gear. Both the horizontal and vertical circles are made of optical glass and are etched with two concentric sets of gradu-

ations in the sexagesimal system. The outer set consists of single lines and the inner set double lines. The images of diametrically opposed portions of the circles appear superimposed in the reading window, and "coincidence" is effected by placing the single graduations symmetrically within the double graduations. The same micrometer knob is used to bring either the vertical or horizontal circle into coincidence. The vertical circle, horizontal circle, and micrometer reading windows appear from top to bottom in a single reading eyepiece located below the telescope eyepiece. (See Figure 6)



$$
\begin{array}{r}
63^\circ 10' \\
0' 46''.2 \\
\hline
63^\circ 10' 46''.2
\end{array}
$$

Figure 6 EXAMPLE READING OF VERTICAL CIRCLE

The least graduation value on the circles is 10 minutes. The micrometer has a range of 5 minutes, a least graduation of 0.5 seconds, and may be estimated to the nearest 0.1 second. A triangular index appears in each circle reading window, and is used to read the circle to the multiple of five minutes next below the exact reading. The remaining minutes, seconds, and decimal part of the second are then read from the micrometer, and added to the above value.

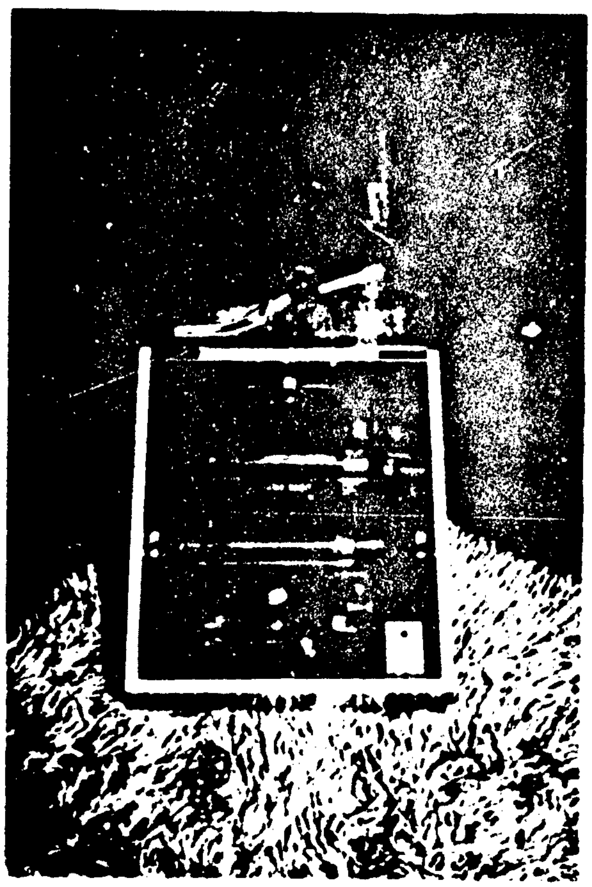
The horizontal circle graduations increase in a clockwise direction. The vertical circle reads 0° at the zenith and increases in a counter clockwise direction. Since the instrument is not equipped with any type of setting circle, the vertical circle must be used to set zenith distances. The triangular index may be used to estimate minutes directly for star pick-up purposes. If the instrument is in an ocular east position, the vertical circle reads zenith distances of south settings directly, and 360° minus zenith distances for north settings. The reverse is true for ocular west. For precise vertical circle readings, the vertical collimator bubble must first be put in coincidence.

Elaborate laboratory tests of the plates, micrometers, and reading techniques utilized in the DKM3 and subsequently the DKM3-A, have confirmed the outstanding precision and consistency of all the mechanical and optical

components (5) and (11).

1.7 Levels

The DKM3-A is equipped with both a striding level and double Horrebow levels. (See Figures 1 and 7)



1. Striding Level 2. Horrebow Level

Figure 7 STRIDING AND HORREBOW LEVELS IN CARRYING CASE

The striding level is not set directly on the horizontal axis, but is supported by two seats that are parallel to the axis and rigidly attached to the standards. The level is heavily weighted for stability, and can be placed on the instrument in only one position, i.e. the level cannot be reversed on the seats. A centering adjustment screw is conveniently located at one end of the vial housing. The striding level cannot be used during Horrebow-Talcott latitude determinations because it interfers with the viewing of the Horrebow levels.

The Horrebow levels are designed to be attached only after the instrument has been set up. A counter weight is attached to the instrument during shipment, and must be removed before the Horrebow levels can be mounted. Three screws connect the Horrebow mount to the instrument directly opposite the observing ocular. The bubbles may be clamped to the horizontal axis with the telescope in any position and a slow motion tangent is provided for final adjustment. One bubble mount is provided with a centering adjustment screw to facilitate alignment of the two bubbles. The entire bubble mount must be removed in order to adjust the bubbles' lengths.

The vials used in both the striding and Horrebow levels are of the chamber type and have sensitivities of approximately 1.5 seconds of arc per 2 mm division.

There are approximately 40 viewable divisions and every fifth division is numbered in a continuous scheme throughout the length of the vial. The striding level's numbering increases toward the observing ocular. One of the Horrebow level's numbering is biased by 100 to eliminate any confusion in readings, and the numbering increases from the observer's right to left, i.e. ocular east, the maximum values are to the south. The bubbles are all read as reflected images viewed in overhead mirrors. Lighting units are available for both the striding and Horrebow levels.

The instrument is further equipped with a plate level with a sensitivity of approximately 10 seconds of arc per 2 mm division and a graduated collimation bubble for which vials with sensitivities from approximately 10 to 2.5 seconds of arc per 2 mm division are available. The collimation bubble is viewed as a split image in a rotatable prism mounted at the top of the standard nearest the observer, and is brought into coincidence by use of the collimation level slow motion screw.

1.8 Leveling System

The DKM3-A eliminates many of the instabilities inherent in leveling screws by the use of Kern's system of leveling cams. A cam on the intersurface of each leveling knob bears on the inclined supporting surface of a boss provided on the instrument's anchor plate. As the

leveling knob is turned about its horizontal axis the instrument is raised or lowered. The weight of the instrument acting on the system assures that it comes to rest at the lowest possible point, and eliminates lateral motion. (See Figure 8)

The system provides a limited leveling range, and therefore requires preliminary leveling of the supporting base. A Kern trivet or tripod meets this requirement.

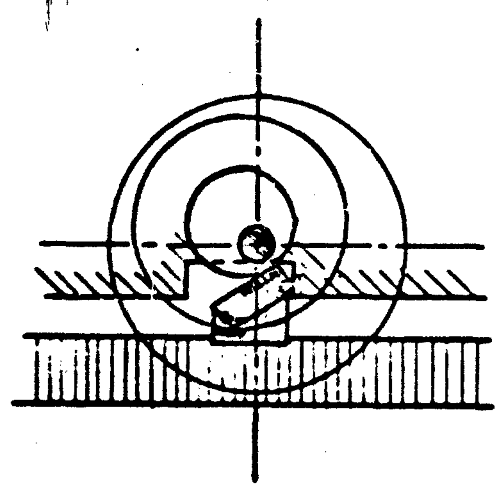


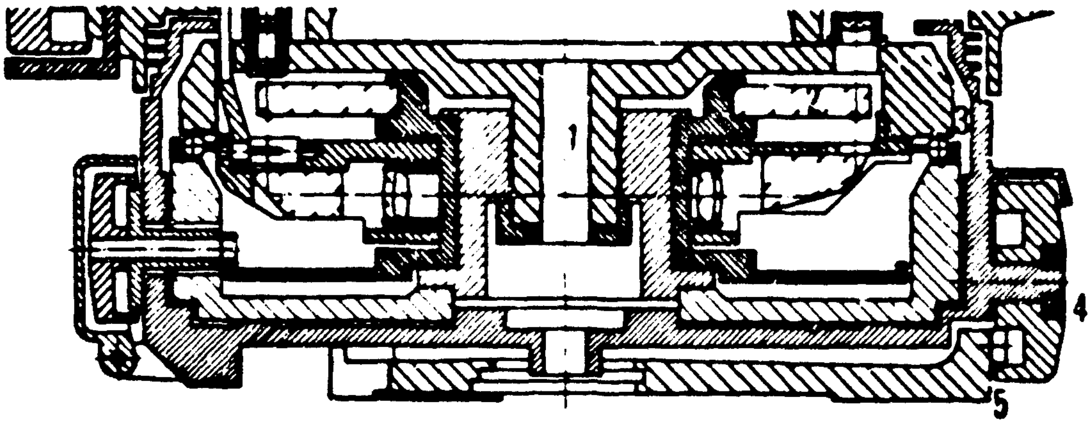
Figure 8 SKETCH OF LEVELING KNOB

1.9 Vertical Axis

The DKM3-A utilizes the Kern precision ball-bearing vertical axis system. (See Figure 9) The basic components of this system are a short vertical axis, approximately 2.5 cm. in length that serves as a centering pivot only and does not support any of the alidade weight and a concentric ring of steel ball-bearings that run

between two optically flat races and support the alidade.

The result is a highly stable, free running system that is particularly insensitive to temperature variations and lubricant viscosities. Inherent instabilities are said to be less than one second.



1. Vertical Axis
2. Horizontal Circle
3. Ball-Bearing Raceway
4. Leveling Knob
5. Anchor Plate

Figure 9 SECTION THROUGH BASE OF DKM3-A

1.10 Optical Plummet

The instrument has an optical plummet mounted in the alidade.

Chapter 2

INSTRUMENT CALIBRATION

2.1 Bubble Sensitivities

The striding level and Horrebow levels bubble vials sensitivities were determined by Kern's Port Chester, New York, office at the time of their installation approximately one week before the beginning of this study.

The calibrations were made against the instrument's vertical circle, and the final accepted value is the result of a series of 5 determinations (22). The sensitivities per division were found to be:

Striding level	$1''.6$	$\pm\ 0''.10$
Horrebow levels	$1''.3$	$\pm\ 0''.10$
	$1''.4$	$\pm\ 0''.10$

2.2 Astronomic Micrometer Constants

The astronomic micrometer was examined to determine the "mean width of contact", the "lost motion", and the "equatorial value".

2.21 Mean Width of Contact

The contact strips used in the astronomic micrometer time recording apparatus have finite widths that cannot be considered negligible for precise time determinations. The individual widths do not vary significantly and a mean value may be used to make the necessary correction.

A mean width determination was made in the field during the process of this study. The results of 10 sets

of measurements, each set consisting of a reading of the width of each of the 10 contacts, yielded a mean width of 0.713 ± .008 drum divisions.

2.22 Lost Motion

If the movable wire is set on some fixed object such as the 10 line of the fixed reticule, once by approaching it from lesser values and once from greater values, the two readings will not be identical. The absolute differance of the readings is defined to be the lost motion of the micrometer.

The lost motion is thought to be effected by the position of the movable wire within the field of view and the position of the telescope in zenith distance. The DKM3-A is satisfactorily equipped for lost motion determination only at the center of the field - at the 10 wire.

For the purpose of this study the lost motion was evaluated for zenith distances of 45°, 30°, and 0°. (vertical circle settings of 45°, 30°, 0°, 330°, 315°) Each determination consisted of a set of 10 readings. Variations in the lost motion were small and yielded a mean lost motion of 0.244 ± .008 drum divisions.

2.23 Equatorial Value

The DKM3-A's astronomic micrometer was designed to have an equatorial value of one turn of approximately two

minutes of arc or 8 seconds of time. Each instrument will have a slightly different value and the value for any particular instrument will change slightly with changes in focus. For this reason, a best fitting equatorial value is computed as part of the least squares adjustment of each latitude determination by the Horrebow-Talcott method.

The equatorial value for the instrument used during this study, as derived from the latitude observations, is approximately $118\overset{''}{.}5$ or $7\overset{s}{.}9$.

2.24 Comments

The micrometer has a rather large amount of lost motion which is usually considered undesirable. Hoskinson and Duerksen (7) warn that the lost motion may vary unpredictably within the field of view, and it is possible that the "stationary lost motion" (determined here) may differ from what might be called the "dynamic" lost motion - this being the lost motion at a point when the screw is rotating rapidly enough for star tracking.

It continues that if the stationary lost motion is nearly zero it is probable that the effect of dynamic lost motion may be ignored, but if this condition is not met, it may be necessary to determine the dynamic lost motion through much more elaborate procedures. Such an

investigation is outside the scope of this field study, but it is mentioned here as a possible source of micrometer error.

Chapter 3

OBSERVATIONAL METHODS AND SPECIFICATIONS

3.1 Introduction

At present there are several U.S. Government Agencies doing precise astronomic latitude and longitude determinations through out the world. While each such organization may have slightly varying techniques and specifications that define various accuracy classifications, the differences are usually insignificant and in general one can group such observations into one of the three following categories - "first-order", "modified-first-order", "second-order".

The less precise second-order methods usually do not require an instrument equipped with an astronomic micrometer and are well suited to instruments such as the Wild T-3 or the Kern DKM-3 theodolites. Several second-order methods are described in detail in (4) and (15).

The more precise first-order and modified-first-order position determinations depend on the Horrebow Talcott latitude method and the Meridian-Transit longitude method. Both observations require the use of an astronomic micrometer and special highly sensitive level systems usually found only on instruments specifically designed for such work.

The following sections give a brief description of the first-order and modified-first-order procedures and

the specifications followed during the observing and computing facets of this study.

3.2 Latitude by the Horrebow-Talcott Method

3.21 Description

The Horrebow-Talcott method for precise latitude determination consists of measuring the difference in meridian zenith distance of two stars at nearly equal altitudes and right ascensions that culminate on opposite sides of the zenith. The small difference in zenith distances is measured by an astronomic micrometer, and Horrebow levels provide a measurement of any meridional inclination of the instrument during the observing period.

The latitude of the observing station is the mean of the declinations of the two stars plus the algebraic sum of one half of the observed micrometer difference, one half of the difference in meridional inclination of the collimation axis during the observations, and one half of the difference in refraction of the two zenith angles. If either or both of the stars is observed prior to or after culmination a correction term must be applied to reduce the observation to the meridian.

The USC&GS adopted the Horrebow-Talcott method as their standard of latitude determination in 1851, and a detailed account of their observational techniques and computations are presented in (7).

3.22 Latitude Equation

While the general Horrebow-Talcott latitude equation is independent of the instrument used, the signs of the micrometer and level terms do depend on the direction and format of the graduations of the scales involved, and therefore the exact latitude equation must be determined for the particular instrument used (2). The equation given below is applicable to observations made with the DKM3-A.

$$\phi = \tfrac{1}{2}(\delta_n + \delta_s) + \tfrac{1}{2} R (M_e - M_w) + \frac{(d + d')}{16} ((n + n' + s + s')_w - (n + n' + s + s')_e) + \tfrac{1}{2} (r - r') + \tfrac{1}{2} (m + m')$$

δ_n, δ_s are the apparent declination of the north and south stars.

M_e, M_w are the micrometer readings with ocular east and west; expressed in whole and decimal parts of turns.

R is the equatorial value of one turn of the micrometer in seconds of arc. An approximate value is used for the initial computation and a best fitting value is determined as a part of the adjustment.

$(n + n' + s + s')_w$, $(n + n' + s + s')_e$ are the Horrebow level readings, north and south ends, with ocular west and east.

$(r - r')$ is the difference in refraction of the two stars, in seconds of arc, and will have the same sign as the

micrometer correction. Tables VIII, VI, and VII of (7) may be used to compute the magnitude of the correction.

(m + m') is the sum of the meridian corrections and is applied only if one or both of the stars are observed prior to or after transit. It can be directly interpolated from Table X of (7).

d, d' are the sensitivities in seconds of arc of each Horrebow level per division.

3.23 Adjustment of Latitude

Individual latitudes differing from the mean latitude by more than $3''.0$ are first rejected. After a new mean latitude, corresponding residuals, and the probable error of a single observation, e_p, have been computed, each remaining observation is examined for possible rejection due to an abnormally high residual to e_p ratio. Chauvenet derived a set of rejection limits based on the number of observations and the residual to e_p ratio from the theory of least squares. Their applications are described in detail in (7). Based on his work, the following rejection criteria have generally been accepted as valid when the number of observations is approximately 20 or more. Any observation with a residual greater than $5e_p$ is automatically rejected. In addition, $3\frac{1}{2}e_p$ is used as a doubtful limit and if additional evidence indicates that an observation's validity is questionable, such as an observer's field note, contradictions in the field

records, or a large probable error of one or both of the stars' declinations as tabulated in the star catalogue, the observation should be rejected. For fewer observations, refer to "Reduction of Doubtful Observations" page 136 of (7).

Subsequent to the above rejections and prior to the final adjustment the algebraic sum of the micrometer differences must be checked to see that it is less than the total number of acceptable pairs. If not, additional star pairs must be rejected on the basis of largest number of micrometer turns and maximum residuals until a sufficent balance is effected.

The accepted latitudes are then adjusted to determine the most probable station latitude. The observation equation set up for each latitude is of the form:

$$c - Mr + \Delta\phi = v$$

Where:

$\underline{c}$ is the amount in seconds of arc by which the arithmetic mean latitude differs from the most probable value.

$\underline{r}$ is the amount in seconds of arc by which the assumed half turn value should be corrected.

$\underline{M}$ is the micrometer difference in turns for the pair.

$\underline{\Delta\phi}$ is the average latitude minus the latitude determined by that pair.

A complete derivation of the observation equation from the latitude equation is given in (17).

If p is the number of accepted latitudes the normal equations become:

$$\begin{aligned} pc - [M]r + [\Delta\phi] &= 0 \\ -[M]c + [MM]r - [M\Delta\phi] &= 0 \end{aligned}$$

Using the $\underline{r}$ determined by solving the normal equations, the individual latitudes are corrected and the mean observed latitude and corresponding residuals, v's, are computed. The probable error of a single observation, e_p, and the probable error of the latitude, e_ϕ, are computed from the formulas:

$$e_p = \pm 0.6745 \sqrt{\frac{[vv]}{p - 2}}$$

$$e_\phi = \pm 0.6745 \sqrt{\frac{[vv]}{(p - 2)\left(p - \frac{[M]^2}{[MM]}\right)}}$$

3.24 Latitude Specifications

A "first-order" latitude determination should depend on approximately 24 acceptable star pairs, 20 being an absolute minimum, giving a probable error (e_ϕ) equal to or less than $\pm$ 0ʺ10. The observations must be made on two or more nights with a minimum of 8 acceptable pairs being observed on any particular night. The algebraic sum of the measured micrometer differences, in turns, must be less than the number of acceptable pairs observed that night. No stars should be observed at zenith distances greater than 45°. Star pairs may not be repeated, but any individual star may be repeated if it is paired with a different star each time. The stars should be

selected from a general star catalogue such as (3).

A "modified first-order" latitude determination should depend on approximately 16 acceptable star pairs, 12 being an absolute minimum, requiring only one night's observations with a maximum probable error of $\pm 0''.20$ or $\pm 0''.25$. All other specifications are the same as for "first-order" determinations.

3.3 Longitude by the Meridian-Transit Method

3.31 Description

The determination of an observer's longitude consists of measuring the difference between the Local Sidereal Time (LST) at the observer and the Greenwich Sidereal Time (GST) at the same instant. The GST is readily attainable in the form of Universal Time, from various radio time signals, and the LST can be determined by observing the meridian transit times of stars-at the instant of transit the LST is equal to the star's right ascension.

In practice, some value is assumed for the observer's longitude and a sidereal chronometer is set to the corresponding LST. The difference between this assumed LST and GST is checked at frequent intervals to determine the chronometer's correction and rate. The transit times of a number of stars are then recorded in reference to the assumed LST. Any difference between the observed time of transit (recorded time of transit corrected for

instrumental constants, instrument dislevelment, and diurnal aberation) and the apparent right ascension of the star consists of a correction to the assumed longitude and a reduction to the meridian. A set of such star observations, selected to fulfill certain specifications, (See 3.33) constitutes one longitude determination or meridian transit.

3.32 Longitude Reductions

An observation equation of the form:

$$\Delta\lambda - Aa + (\alpha - t - \Delta t) = v$$

is formed for each star and a least squares adjustment is performed to determine the best fitting $\Delta\lambda$ and $\underline{a}$ for each set.

Where:

$\Delta\lambda$ is the correction to the assumed longitude.

a is the azimuth of the instruments collimation axis during the observations. (reduction to meridian)

α is the apparent right ascension of the star.

A is the star azimuth factor and can be directly interpolated from Table III (7).

t is the observed time of transit.

Δt is the chronometer correction.

Any star yielding a $\Delta\lambda$ that is greater than $0\overset{s}{.}2$ from the set's mean is rejected. The probable error of $\Delta\lambda$ as determined by a single star, e_s, and the prob-

able error of the set's mean $\Delta\lambda$, e_r, are computed from the acceptable stars using the following equations.

$$e_s = \pm .6745 \sqrt{\frac{[vv]}{n - 2}}$$

$$e_r = \pm .6745 \sqrt{\frac{[vv]}{n(n - 1)}}$$

The probable error of the mean $\Delta\lambda$ of a set should not commonly exceed $\pm$ 0.ˢ025 and if such a determination also differs from the arithmetical mean of all the sets observed by more than 0.ˢ03, or if some other evidence indicates that the determination may not be valid, it may be rejected. Any determination differing from the mean by more than 0.ˢ04 is automatically rejected.

The probable error of a single determination, e_s^λ, and the probable error of the mean longitude, e_r^λ, are computed from equations of the same form as above, where the residuals now refer to the arithmetical mean of all the acceptable determinations.

3.33 Longitude Specifications

A "first-order" longitude is composed of at least 6 (some organizations require 8) longitude determinations with a maximum probable error of the mean longitude of $\pm$ 0.ˢ010. The observations must be made on two or more nights with a minimum of two acceptable determinations being observed on a night different from the others.

Each longitude determination, or time-set, consists

of from 5 to 8 acceptable stars bracketed by radio chronometer comparisons. The stars should be as evenly distributed north and south of the zenith as possible. An acceptable 5 star set must contain 2 north (south) and 3 south (north) stars. The selected stars should have a maximum A-factor of $\pm$ 0.60 and the algebraic sum of the A's for any determination should not exceed $\pm$ 1.00. The instrument should be within $1\overset{s}{.}0$ (a) of the meridian throughout the observations. At least 10 breaks before transit and the corresponding breaks after transit whose sums do not vary more than $0\overset{s}{.}3$ are required for an acceptable star track. The stars are selected from the Apparent Places of Fundamental Stars - FK4 star catalogue.

Each radio-chronometer comparison should be the result of about 20 scaled radio breaks and the decimal portion of any particular break should not vary from the mean by more than $0\overset{s}{.}05$.

A "modified first-order" longitude is composed of at least 3 (4 being more desirable) determinations with a maximum probable error of the mean longitude of $\pm$ $0\overset{s}{.}25$. All of the observations may be performed during one night. All other specifications are the same as the "first-order" determinations.

3.4 Computations

All of the latitude and longitude observations made during this study were computed by the 1381st GSS's

electronic computer using the same programs they developed to reduce their precise position observations. The rejections of doubtful observations and the final adjustments were done by hand, following the procedures previously outlined.

CHAPTER 4

FIELD OBSERVATIONS

4.1 Station Description

OAFB-60-E is the station designation of the east pillar in the 1381st Geodetic Survey Squadron's Astronomic Observatory located at Orlando AFB, Orlando Florida. (See Figure 10)

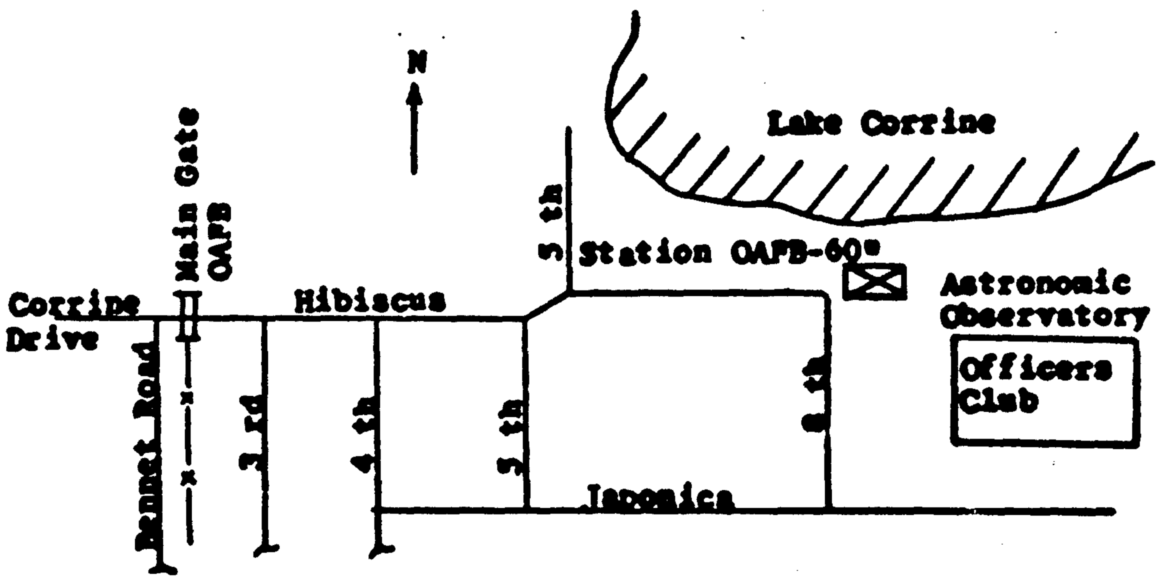


Figure 10 STATION LOCATION

The observatory is a small wooden structure with retractable roof sections and slot type windows that when opened provide a completely unobstructed view of the meridian from the north to south horizons. It houses two isolated concrete pillers suitably designed to support instruments for precise astronomic observations. Figure 11 is a picture of the observatory as viewed from the

north.

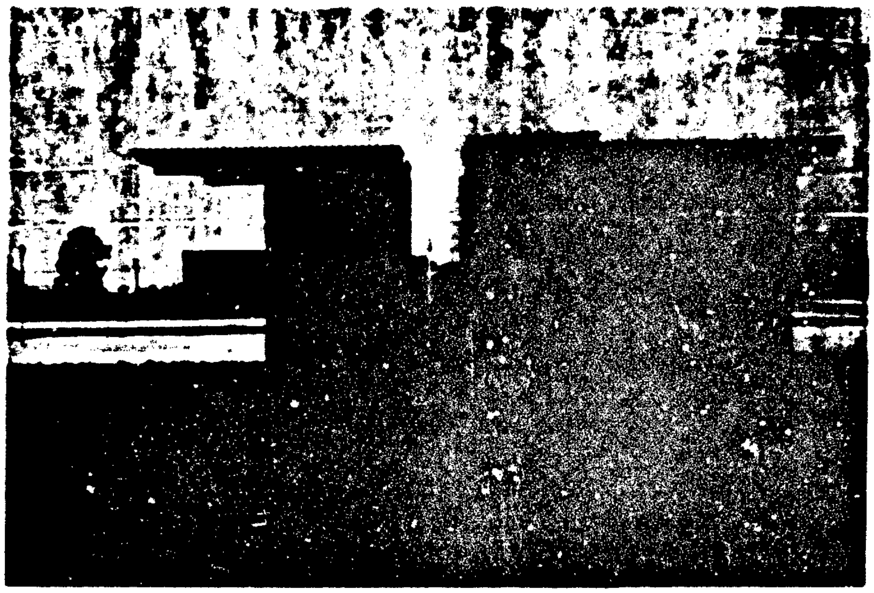


Figure 11 THE 1381st GSS ASTRONOMIC OBSERVATORY

The observatory has been in nearly constant use since its construction for training Air Force personnel in the use of the Wild T-4 Universal Theodolite for precise astronomic latitude and longitude determinations. The station coordinates may be assumed to be quite accurately known and provide an excellent standard against which the DKM3-A results may be compared.

The astronomic observations made in the observatory are reduced to the geodetic station OAFB-60 located $0^s.004$ west and $0''.36$ north of OAFB-60-E. The station elevation is approximately 30 meters, which means that the reduction

to the geoid may be considered to be zero. The astronomic coordinates of station OAFB-60 are:

Latitude 28° $34'$ $03''.60$ North

Longitude 05^h 25^m $17^s.355$ West

The latitude refers to the B.I.H. pole. The longitude is refered to the UT2 time system, and includes a correction to reduce it to the prior 1960 WWV system. (See Section 4.7)

4.2 Auxiliary Equipment

All of the equipment used during the field observations, other than the DKM3-A, belongs to the 1381st GSS. The equipment was purchased specifically for precise astronomic work and is of the highest quality.

A Nardin two-second break circuit sidereal chronometer, electric drum type chronograph and an astronomic amplifier were used for recording the time signals and times of star transits for longitude observations. A Zenith Transoceanic radio was used to receive the radio time signals. A tapeing thermometer and a pocket barometer provided field temperatures and barometric pressures, and the readings were checked frequently against those obtained from the McCoy AFB weather station. (See Figure 12)

1. DKM3-A
2. Zenith Transoceanic RADIO
3. Astronomic Amplifier
4. Drum Chrongraph
5. Nardin Sidereal Chronometer

Figure 12 DKM3-A WITH AUXILIARY EQUIPMENT

4.3 Observers

While the observers were all experienced in making first-order position observations with the Wild T-4, unfortunately they had no prior experience with Kern instruments. Changes in instrumentation are especially effectual to longitude observations, and even minor changes in such physical items as the spacing and diameter of the tracking knobs and the micrometer's tracking ratio create a change in what may be described as the "feel" of the instrument. As a result the observer

may find it difficult to track a star as smoothly as normal, and the accuracy of the time of transit becomes questionable. Readings from the unfamiliar plates and micrometer are also more prone to errors.

The time available for the field work portion of this study was limited and bad weather further restricted the number of observations that could be accomplished. The result was that the observers had only the most limited time in which to become familiar with the DKM3-A, and some of the first longitude star tracks were rather inconsistent. As the observers experience with the instrument increased, the works consistency also increased.

4.4 Weather

The weather was a significant factor during this study. The observations were begun on the 31st of August 1964 and there followed about one week of fairly clear weather in which 3 first-order latitudes and 2 first-order longitudes were observed. During this time a large hurricane, Diane, was approaching the station from very nearly due east, and on the 10th of September passed just north of Orlando bringing winds in excess of 80 miles per hour and over 8 inches of rain to the area. Observations were resumed on the 13th, but the weather continued to be rather unstable throughout the remaining observations.

It is very difficult to determine just what effect the approach or retreat of such severe weather could have

on astronomic observations. It is known that the phenomenon known as a "tilted atmosphere" (tilted isotherms, isobars, air densities) can cause significant local lateral refraction and (1) has recorded correlation between wind conditions and apparent changes of longitude. Estimations of the magnitude of such atmospheric effects vary greatly with investigators.

4.5 Latitude Observations

A total of 4 first-order and one modified-first-order latitudes were observed by 5 different observers. The results are tabulated in Table 1 . The mean observed latitude was computed using a weight of $\frac{1}{e_\phi^2}$ for each determination.

4.6 Analysis of Latitude Results

The latitude determinations are what might be described as "typical" Horrebow Talcott latitude observations. The maximum variation in the final observed latitudes, uncorrected for polar motion, is 0$''$24. The mean correction to the provisional B.I.H. pole (23) over the period of these observations was approximately + 0$''$02. If the correction is added to the mean observed latitude, the final mean latitude becomes 28° 34' 03$''$63. The latitude as determined by the DKM3-A agrees with the station latitude, as determined by the T-4, and it seems likely that no "instrument equation" exists between the two instruments.

LATITUDE OBSERVATIONS					
Observer	Date	Pairs	Observed Latitude	e_p	e
1	31 Aug. 2 Sept.	15 12	28° 34' 03."34	±0."47	±0."09
2	1 Sept. 3 Sept.	15 12	03.10	0.46	0.09
3	5 Sept. 6 Sept.	15 10	03.22	0.50	0.11
4	13 Sept. 17 Sept.	16 16	03.32	0.38	0.07
5	18 Sept.	16	03.10	0.63	0.16
Mean Observed Latitude			28° 34' 03."25		
Reduction to OAFB-60			+ 0.36		
Mean Observed Latitude of Station OAFB-60			28° 34' 03."61	±0."04	

Table 1 LATITUDE OBSERVATIONS AND RESULTS

4.7 Longitude Observations

A total of 29 longitude determinations (sets) were observed by 3 different observers during this study. Table 2 gives a schedule of the observations and lists the observations rejected.

Tables 3, 4, and 5 give summaries of the accepted observations by each observer, and contain the final

reduction to the geodetic station. The observed values have been corrected to UT0 time, and a provisional UT2 value, based on the provisional correction (23) is also given. The U.T. correction was added to reduce the longitude to the system used prior to 1960. The correction is the result of a change in the accepted longitude on which the WWV radio time signals are based (19) and (20). The mean observed longitude, computed from the provisional UT2 values using a weight of $\frac{1}{(e_{\frac{1}{r}})^2}$ for each determination is $05^h\ 25^m\ 17.^s350 \pm 0.^s011$.

LONGITUDE OBSERVATIONS				
Observer	Date	Number of Sets Observed	Sets Rejected	Total Rejected
1	4 Sept.	4	1 & 4	2
	5 Sept.	4	1 & 4	2
	6 Sept.	3	None	0
2	7 Sept. (morning)	2	None	0
	7 Sept. (night)	6	1 & 3	2
	17 Sept.	2	1 & 2	2
3	16 Sept. (morning)	4	4	1
	16 Sept. (night)	4	3	1
Total		29		10

Table 2 SCHEDULE OF LONGITUDE OBSERVATIONS AND REJECTIONS

LONGITUDE DETERMINATION OBSERVER 1

Date	Longitude	e_s	e_r
4 Sept.	$05^h\ 25^m\ 17^s.316$	$\pm 0^s.016$	$\pm 0^s.006$
	17.319	.042	.017
5 Sept.	17.309	.047	.019
	17.326	.050	.023
6 Sept.	17.318	.079	.032
	17.346	.047	.019
	17.334	.037	.015
Mean	$05^h\ 25^m\ 17^s.324$	$\pm 0^s.009$	$\pm 0^s.003$

Mean Observed Longitude	$05^h\ 25^m\ 17^s.324$ (West)
U.T. Correction	+ 0.044
UTO - Signal	- 0.026
Reduction to OAFB-60	+ 0.004
Astronomic Longitude (UTO)	$05^h\ 25^m\ 17^s.346$
Provisional Correction UTO to UT2	- 0.010
Astronomic Longitude Provisional UT2	$05^h\ 25^m\ 17^s.336$

Table 3 SUMMARY OF LONGITUDE - OBSERVER 1

LONGITUDE DETERMINATION			OBSERVER 2
Date	**Longitude**	e_s	e_r
7 Sept. (morning)	$05^{h}\ 25^{m}\ 17^{s}.298$	$\pm 0^{s}.057$	$\pm 0^{s}.025$
	17.328	.042	.017
7 Sept. (night)	17.306	.027	.012
	17.321	.046	.019
	17.350	.065	.027
	17.311	.045	.018
Mean	$05^{h}\ 25^{m}\ 17^{s}.319$	$\pm 0^{s}.009$	$\pm 0^{s}.005$

Mean Observed Longitude	$05^{h}\ 25^{m}\ 17^{s}.319$ (West)
U.T. Correction	+ 0.044
UT0- Signal	- 0.027
Reduction to OAFB-60	+ 0.004
Astronomic Longitude (UT0)	$05^{h}\ 25^{m}\ 17^{s}.340$
Provisional Correction UT0 to UT2	- 0.011
Astronomic Longitude Provisional UT2	$05^{h}\ 25^{m}\ 17^{s}.329$

Table 4 SUMMARY OF LONGITUDE - OBSERVER 2

LONGITUDE DETERMINATION		OBSERVER 3	
Date	Longitude	e_s	e_r
16 Sept. (morning)	$05^h\ 25^m\ 17^s.369$	$\pm 0^s.027$	$\pm 0^s.011$
	17.379	.021	.009
	17.361	.051	.018
16 Sept. (night)	17.396	.028	.011
	17.374	.021	.014
	17.399	.062	.025
Mean	$05^h\ 25^m\ 17^s.380$	$\pm 0^s.011$	$\pm 0^s.004$

Mean Observed Longitude	$05^h\ 25^m\ 17^s.380$ (West)
U.T. Correction	+ 0.044
UT0 - Signal	- 0.031
Reduction to OAFB-60	+ 0.004
Astronomic Longitude (UT0)	$05^h\ 25^m\ 17^s.397$
Provisional Correction UT0 to UT2	- 0.014
Astronomic Longitude Provisional UT2	$05^h\ 25^m\ 17^s.383$

Table 5 SUMMARY OF LONGITUDE - OBSERVER 3

4.8 Analysis of Longitude Results

A total of 10 sets of longitude were rejected after computation. While the number of rejects does seem exceptionally high the reasons for the rejections are significant and must be considered before any conclusions can be made.

Three sets were rejected due to gross misalignment of the instrument in azimuth, on two or more stars of a set, of such magnitude that could only result from the observer misreading the horizontal plate. These rejections could be directly attributed to observer inexperience with the instrument. In addition, 2 sets observed by Observer 2 on the 17th of September, some ten days after his other observations, agreed closely with each other, but differed from the mean of all his observations by more than $0\overset{s}{.}04$. They did agree very closely with observations made by Observer 3 on the two immediately prior nights. The marked difference in the observations made by the same observer might well have been caused by the severe changes in the weather conditions, particularly a change in the wind direction, or to changes in the auxiliary equipment used, or to a combination of such unknown factors. Similar observations have been recorded using accepted "first-order" instruments. The remaining rejections were due to residuals in excess of $0\overset{s}{.}04$ or a combination of high residuals and high probable error

of the set.

No effort was made to rescale the star transit times, an operation that can sometimes change the $\Delta\lambda$ as determined by a set significantly. When such a condition exists it usually is related to observations that have inconsistant star tracks, which are indicative of bad visibility or observer inadequacies rather than the instrumentation. It seems wiser to simply reject such work.

CHAPTER 5

PRACTICABILITY OF THE DKM3-A AS A FIELD INSTRUMENT

5.1 Introduction

The design and production of a highly precise field instrument is as much an art as an engineering feat. Accuracy, feasibility, durability, reliability, portability, compactness, weight, observer convenience, cost, maintainence, and versitility are just a few of the factors that must be considered. It is not always possible to find a solution that fulfills all the requirements as completely as one might desire, and compromises are inevitable. Indeed, even the most qualified critics may disagree on the merits and liabilities of the most basic components of a field instrument.

This chapter contains the favorable and adverse criticisms and suggestions of the five observers that used the instrument during this study. They do not necessarily represent unanimous opinions and I would expect that other users may disagree with some of the statements.

5.2 Telescope

As a part of this study, simultaneous observations were made on the same stars with a DKM3-A and a T-4. The star images appeared to be slightly smaller, but of equal or slightly greater intensity in the DKM3-A.

The instrument's superior lighting and focus systems

and the elimination of nearly all stray light (observations of the stars as dim as 7.0 magnitude were made in a lighted observatory) makes it possible to produce exceptionally sharp star images over a wide range of magnitudes.

5.3 Focusing

Focusing of both the star image and the reticule pattern is quickly, concisely, and conveniently accomplished by the focus knob and ocular focusing ring.

It would seem wise to have the focus knob capped to prevent the possibility of accidental unknown changes in focus, since even small changes in focus could have adverse effects on observations such as latitude.

5.4 Astronomic Micrometer

The DKM3-A's astronomic micrometer has many substantial improvements incorporated into its design.

The optically read "drum scale" is especially praiseworthy. The bold, easily read numbers and graduations are very evenly illuminated by the tinted rheostatically controlled internal lighting system - a combination that not only reduces eyestrain to a minimum but makes misreading very unlikely. The differences between this completely optical system and the graduated-knob system, such as employed by the T-4, are reminiscent of the differences in the plate reading systems of the internally

lighted optically read theodolite and the double-circle vernier read engineer's transit.

One seemingly valid adverse criticism of the DKM3-A's drum-scale is the use of 120 divisions. While this does make each graduation very nearly equal to one second of arc, equatorial value, any minor advantages that might result from such a condition are more than offset by the sacrifice of a decimal relationship between the whole turns as determined by the reticule lines and the fractional turns as read from the drum scale. This adds unnecessarily to the computations and is a possible source of error.

The clamping knob allows the micrometer to be rotated from the azimuth to zenith distance measuring position, or back, without changing focus or using any accessory tools. This is not only an observer convenience, but a time saver as well.

The selection of the approximate equatorial value is a very important consideration in the design of an astronomic micrometer. The entire tempo of star observations and the attainable accuracies of certain determinations are directly effected by the equatorial value selected.

It is important that during longitude determinations the observer has sufficient time to properly accomplish all the necessary readings and reversing operations between the end of the track-in and the beginning of the

track-out of any star. Common practice is for the observer to pick up the star slightly outside the 5 (15) wire and track the star approximately 2½ turns, thus leaving off at about 2½ to 2¾ turns from transit. Since he will begin the track-out from that same point he must be able to perform all of the necessary operations and be ready to begin the track-out in the time required for the star to travel about 5½ turns. With the DKM3-A this is about 45 seconds for equatorial stars.

During the course of this study numerous stars of very low declinations were observed. With only a minimum of practice the observers were able to meet the time requirement.

The most important, demanding, and fatigueing duty of the observer during longitude observations is the actual tracking of the stars. It is an advantage then to reduce the tracking time to a minimum, consistant with the required accuracy, because it is likely that the observer efficiency and accuracy will diminish as he tires. The DKM3-A requires 20% less tracking than the T-4 - a significant reduction.

5.5 Horrebow Level System

The Horrebow level system in its present form is adequate, but somewhat cumbersome under field conditions. The actual operating and reading of the levels once they

havebeen mounted and adjusted creates no difficulties. The vials are clearly marked and conveniently read in the overhead mirror. The internal bubble lighting system was not used during this study, at the recommendation of the manufacturer, but either the instruments hand lamp or an ordinary flashlight provided adequate lighting.

The differences in instrumental meridian inclinations as determined by the two different vials were small, in the order of $\pm$ 0"10 and showed no correlation to the degree of instrument dislevelment. The major source of the differences is likely due to random reading inaccuracies.

The Horrebow level mount is not desirable for field operations. In order to adjust the bubbles' lengths which requires dumping the vials, the entire mount must be removed from the instrument. With bubbles of such high sensitivity it is very difficult to accurately determine the bubbles' lengths until the entire system has been remounted and the bubbles have had time to come to rest. It may sometimes be necessary to repeat the process several times before both bubbles can be made the desired length. The process can be time consuming, produce excessive wearing of the system and create opportunities for damaging the instrument and levels. The

system does have the advantage that the levels cannot be accidentally dumped during the course of observations, but this is of little significance to experienced observers.

A more desirable system, that could be achieved through minor instrument modification, would permit the easy removal of the levels alone. The mount would then be semi-permanent in nature (the entire mount would not normally be removed in the field) and only the levels would be removed during transporting. The bubbles' lengths would be more easily adjusted, danger of instrument damage would be minimized, and the advantage that the bubbles could not be accidentally dumped would not be sacrificed. The entire system would still be relatively easily removed for maintainence.

5.6 Leveling Knobs

The leveling knobs tend to be slightly stiff to operate, especially when the heavily weighted striding level is in place, and make fine leveling a rather tedious procedure. Consequently, minor "touch-up" leveling during an evenings work is not easily accomplished and if the instrument drifts outside the level tolerance the entire leveling procedure must be repeated. The disadvantage is minimized by the excellent stability of the instrument and the end result is a relatively desirable system.

5.7 Setting Zenith Distances

It was mentioned in Section 1.6 that the DKM3-A does not have an auxiliary setting circle, such as the T-4, and therefore the telescope must be set to the proper zenith distance for star pick-up using the vertical circle.

Any doubts about the systems adequacy were quickly dispelled as the observers found that settings could be made with an accuracy of about ± 1 minute of arc in a matter of seconds. The exceptionally short telescope can be manipulated with one hand, leaving the other hand free to operate the vertical clamp, while viewing the plate through the reading ocular. A setting circle is not only not needed, but would most likely prove a hindrance to the observer.

5.8 Additional Factors and Conclusions

There are many small items that may not seem important in themselves, but never the less significantly effect the DKM3-A's value as a field instrument.

The optical plummet provides a convenient method for accurately centering the instrument over a mark - an important requirement for azimuth determinations. Prism eyepieces are available for use during observations such as azimuth or triangulation. The lighting system, completely rheostatically controlled, is excellent

throughout the instrument. The instrument's control knobs are very conveniently located.

The tool kit that is included with the instrument and located in the base of the carrying base is not completely adequate. The auto-collimator light housing tends to interfer with one of the micrometer tracking knobs. The deeply recessed alidade level is rather difficult to view.

These are just a few of the items that add and detract from the DKM3-A, and effect an observer's overall opinion of the instrument.

The reactions of the five observers that used the DKM3-A during this study could only be described as enthusiastic. The instrument shows every sign of being an excellent field instrument.

CHAPTER 6

CONCLUSIONS

6.1 Accuracy

The results of the limited number of observations made during this study indicate that the DKM3-A is capable of producing both first-order latitude and first-order longitude determinations as defined in Chapter 3 of this thesis.

The instrument's latitude capabilities have further been confirmed by an informal test conducted by the USC & GS in May of 1964 (18). The Geodetic Survey of Canada is presently making an extensive field test of the DKM3-A involving observations on 27 field stations. The results of that test should produce more reliable conclusions about its attainable accuracies (6).

6.2 Field Characteristics

The DKM3-A is an excellent field instrument from the viewpoints of portability, versatility, and observer convenience. While very little can be concluded about an instruments durability, required maintainance, dependability, and such related long term considerations from a test of such short duration, the DKM-3 has already proven that the basic mechanical and optical components are sound, and it is likely that the DKM3-A will prove adequate in these respects also. The additions of the

astronomic micrometer, weighted striding level, and double Horrebow level do add considerably to the weight that the vertical axis system must support, and its effect on the life of the system could prove significant. A field instrument can only prove itself after years of use under varying conditions, but the DKM3-A appears to have all the necessary ingredients to make it a valuable addition to the geodesists' array of tools.

BIBLIOGRAPHY

(1) Bamford, A. J. — Report of the Columbia Observatory (1927)

(2) Bomford, G. — Geodesy second edition, Oxford University Press, London, England (1962)

(3) Boss, B. — General Catalogue of 33342 Stars for the Epoch 1950, Carnegie Institute, Washington D.C.

(4) Connor, V. L. — Second Order Astronomic Position Determination, A Thesis Presented in Partial Fulfillment of the Requirements for the Degree Master of Science, Ohio State University, Columbus, Ohio, (1964)

(5) Fondelli, M. — Examination of the Precision of the Kern DKM3 Theodolite, Research Department, the Military Geographic Institute, Florence, Italy

(6) Gregerson, L.F. — Letter to Author, December 21,1964, Department of Mines and Technical Surveys (Geodetic Survey of Canada) Ottawa, Canada

(7) Hoskinson, A. J. and Duerksen, J. A. — Manual of Geodetic Astronomy, U.S. Coast and Geodetic Survey Special Publication No. 237, U.S. Government Printing Office, Washington D.C. (1952)

(8) International Astronomic Union — Apparent Places of Fundamental Stars, FK-4 Astronomisches Rechen Institute, Heidleberg, Germany, (1964)

(9) Kern & Co. Ltd. — Instruction Manual Kern DKM3 First Order Theodolite, Aarau, Switzerland

(10) Kern & Co. Ltd. — Instruction Manual Astronomical Double Circle Theodolite DKM3-A Aarau, Switzerland

BIBLIOGRAPHY

(11) Kneissl, M. "Examination of the Horizontal Circle of the Kern DKM3", Bulletin 6, Kern & Co. Ltd., Aarau, Switzerland

(12) Lamping, N. E. An Investigation of the Personal Error in the Longitude Micrometer of the Astronomical Theodolite, A Thesis Presented In Partial Fulfillment of the Requirements for the Degree Master of Science, Ohio State University, Columbus, Ohio (1964)

(13) Nautical Almanac Office of the U. S. Naval Observatory The American Ephemeris and Nautical Almanac for the Year 1964 U. S. Government Printing Office, Washington, D. C.

(14) Odermatt, H. Instructions for the Determination of Geographic Position, Henry Wild Survey Instrument Supply Company, Ltd. Heerbrugg, Switzerland

(15) Passauer, J.L. An Investigation of Combined Methods of Second Order Astronomic Position Determinations, A Thesis Presented in Partial Fulfillment of the Requirements for the Degree Master of Science, Ohio State University, Columbus, Ohio (1964)

(16) Smart, W. M. Textbook on Spherical Astronomy The University Press, Cambridge, England (1962)

(17) Sukman, L. I. The Effect of the Instrumental Constants on the Determination of Astronomic Positions, A Thesis Presented in Partial Fulfillment of the Requirements for the Degree Master of Science, Ohio State University, Columbus, Ohio (1962)

BIBLIOGRAPHY

(18) Thorson, C. W. Letter to Author, August 13, 1964
U.S. Coast and Geodetic Survey
Washington, D.C.

(19) U.S. Naval Observatory Time Service Notice No. 9
21 December 1960, Washington D.C.

(20) U.S. Naval Observatory Time Service Notice No. 42
10 January 1962, Washington D.C.

(21) U.S. Naval Observatory Time Service Weekly Notices
180, 181, 182, 183 and 184 for the
month of September 1964

(22) Wehrli, H. J. Letter to Author, October 2, 1964
Kern Instrument Inc. , Port Chester,
New York

(23) 1381st Geodetic Survey Squadron
Observation and Computation Instructions for Astronomic Position
Determinations, Orlando AFB, Orlando,
Florida